Title of Investigation:

A Ditherless Quadrature Phase Detector for Space Interferometry

Principal Investigator:

Richard K. Barry (Code 667/601)

Other In-house Members of Team:

William C. Danchi (Code 667)

Other External Collaborators:

None

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$25,000

Funding Authorized for FY 2005:

$25,000

Actual or Expected Expenditure of FY 2005 Funding:

$25,000

Status of Investigation at End of FY 2005:

To be transitioned for use in the Fourier-Kelvin Stellar Interferometer Testbed project in FY 2006

Expected Completion Date:

End of FY 2006

Purpose of Investigation:

Typically, modern optical and infrared stellar interferometers measure the sizes and shapes of astronomical objects by combining the light from two or more telescopes. The wavefront that comes in from each telescope must then be brought together precisely and superimposed at a single detector to form a light fringe that then can be analyzed. To do this, the pathlengths through which each wavefront travels must be made equal to within a fraction of a wavelength of light. The phase of the light, or its position in space in the direction that it is traveling, must be detected and controlled. The wavefront's phase is typically detected by electromechanically dithering a mirror in the lightpath to change the relative pathlength that one beam of light travels. This physical movement takes time. The purpose of this DDF is to develop a system that replaces physical delay with optical delay. This is called the delay. Measurements of the strength of the combined light are then taken periodically as the fringe is dithered or slewed back and forth in the direction of the light's motion using a repetitive saw-tooth drive wave delivered to an actuator that controls physical delay.

In the dithered case, simple phase-detection algorithm is subsequently used to derive the phase from these measurements. The phase, given as assigned error signal, which the control system seeks to minimize in magnitude, is then conditioned into a drive signal. This drive signal is used to change the relative pathlength so that the amount of contrast between the brightest and darkest parts of the combined light fringe—called the visibility—is consistently measured. The use of this approach to sense and control the fringe phase requires considerable time per cycle. This results in a typically slow, low-bandwidth response. A more efficient possibility is to introduce the phase shifts optically rather than electromechanically and make all measurements simultaneously to produce the error signal. This could considerably stiffen the control system response and should result in greater fringe contrast, as there will be less movement of the fringe between measurements. This should, in turn, allow improvements to the overall sensitivity of instruments, as the integration time will not be fixed by the dither frequency of the electromechanical transducers. This is typically the principal source of bandwidth limitation in any closed-loop system. The Ditherless Quadrature Phase Detector (DQPD) is being developed through this DDF for this purpose.

Accomplishments to Date:

The DQPD is being developed contemporaneously with the Fourier-Kelvin Stellar Interferometer (FKSI) testbed project and may be integrated into it depending on test results. DQPD's optical breadboard has been designed and is being built in Goddard's Horizontal Flow Facility on an optical table near the FKSI nulling testbed.

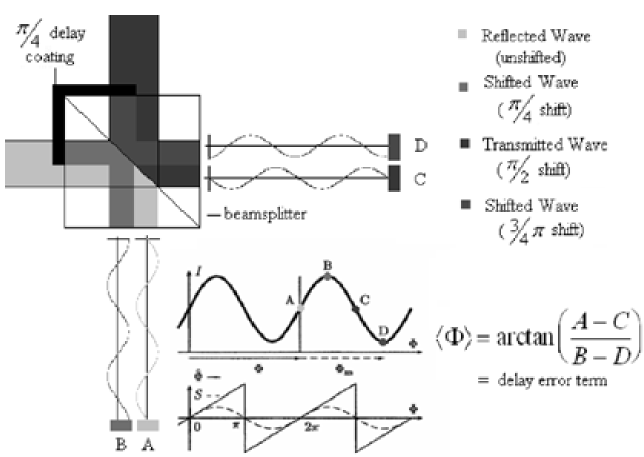

Figure 1. The Ditherless Quadrature Phase Detector

The principle behind DQPD may be easily understood by examining Figure 1. This proof-of-concept design uses two beams, which are combined in a specially coated beam splitter. The coating, which delays half of the beam by $1/4\ \pi$, is applied directly to the beam splitter, which is slightly wedged to reduce ghosting. The $1/2\ \pi$ phase delay produced by transmission through the beam splitter results in the needed spread of measurements, which may be accomplished simultaneously using four detectors. The control system then rapidly calculates the required error signal as indicated in the figure. The optical breadboard is shown schematically in Figure 2.

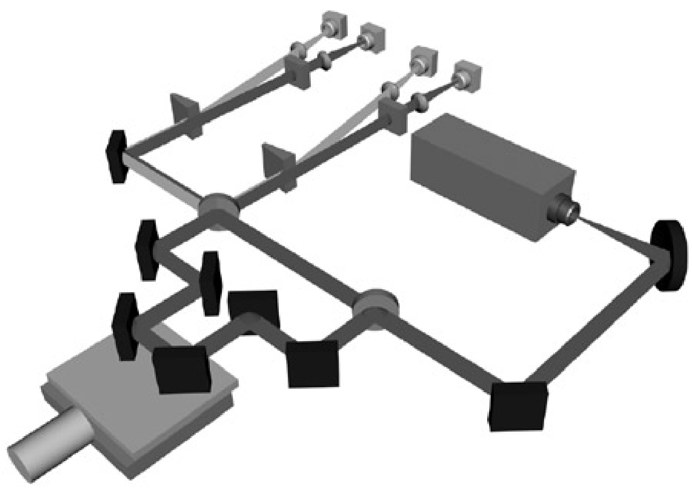

Figure 2. Schematic Optical Breadboard

Challenges for this phase-sensor design are principally associated with our approach of using spatially separate portions of the wavefront to measure fringe power at different phases. If there are departures from ideal wavefront flatness or tilt, the error signal derived from the sensed phase will either have a systematic error term, which could be calibrated out, or will be noisy. We are now exploring designs that sample the same spatial patch of the wavefront at different polarizations or clean the wavefront and correct its tilt prior to sensing. Figure 3 shows the working breadboard of this concept.

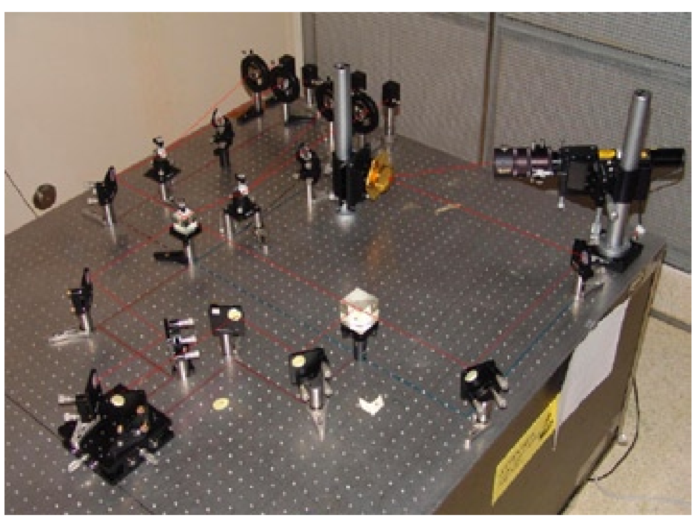

Figure 3. Photograph of functioning optical testbed

This work has been both published and presented in the following publications and venues:

Barry, R.K., Danchi, W.C., Chambers, V.J., Rajagopal, J., Richardson, L.J., Martino, A.J., Deming, D., Kuchner, M., Linfield, R., Millan-Gabet, R., Lee, L. A., Monnier, J.D., L. G. Mundy, C. Noecker, S. Seager, D. J. Wallace, R. J. Allen, W. A. Traub, and H. C. Ford, "The Fourier-Kelvin Stellar Interferometer (FKSI): A progress report and preliminary results from our nulling testbed", in Techniques and Instrumentation for Detection of Exoplanets II, edited by Daniel R. Coulter, *Proc. SPIE*, Vol. 5905, 57 (2005).

Barry, R. K., Danchi, W. C., Deming, L. D., Richardson, L. J., Kuchner, M. J., Chambers, V. J. Frey, B. J., Martino, A. J., Rajagopal, J., Allen, R. J., Harrington, J. A., Hyde, T. T., Johnson, V. S., Linfield, R., Millan-Gabet, R., Monnier, J. D., Mundy, L. G., Noecker, C., Seager, S. and Traub, W. A., "The Fourier-Kelvin Stellar Interferometer: an achievable, space-borne interferometer for the direct detection and study of extrasolar giant planets," in *IAUC 200, Direct Detection of Exoplanets: Science and Techniques*, Aime, C. and Vakili, F., eds., submitted November 2005.

Planned Future Work:

The Ditherless Quadrature Phase Detector (DQPD) is being developed contemporaneously with the FKSI testbed project and may be integrated into it depending on test. The optical breadboard for the DQPD has been designed and is being built in Goddard's Horizontal Flow Facility on an optical table near the FKSI nulling testbed. We expect to complete this work during FY 2006.

Key Points Summary:

Project's innovative features: The project offers a more efficient possibility for measuring optical phase in an interferometer. This will be accomplished by introducing phase shifts optically rather than by dithering the pathlength electromechanically. Measurements that were previously made sequentially can now be made simultaneously to produce a needed error signal in about one quarter of the time. This is an unprecedented approach.

Potential payoff to Goddard/NASA: This approach could considerably stiffen control system response for systems that implement this technique and has the potential to greatly increase system reliability. Furthermore, in the case of interferometric systems, it should result in greater fringe contrast. With greater fringe contrast, there is an increased possibility of obtaining scientific data of a quality that could, for instance, allow the detection of exoplanets or the conduct of high-resolution astronomy of the environments of active galactic nuclei.

The criteria for success: The criterion for success is a measurable increase in null fringe contrast while the system is engaged.

Technical risk factors: Challenges for this phase sensor design are principally associated with our approach of using spatially separate portions of the wavefront to measure fringe power at different phases. If there are departures from ideal wavefront flatness or tilt, the error signal derived from the sensed phase will either have a systematic error term, which could be calibrated out, or will be noisy. We are now exploring designs that sample the same spatial patch of the wavefront at different polarizations or clean the wavefront and correct its tilt prior to sensing. Figure 3 shows the working breadboard of this concept.